

Superconductor “Sponge”

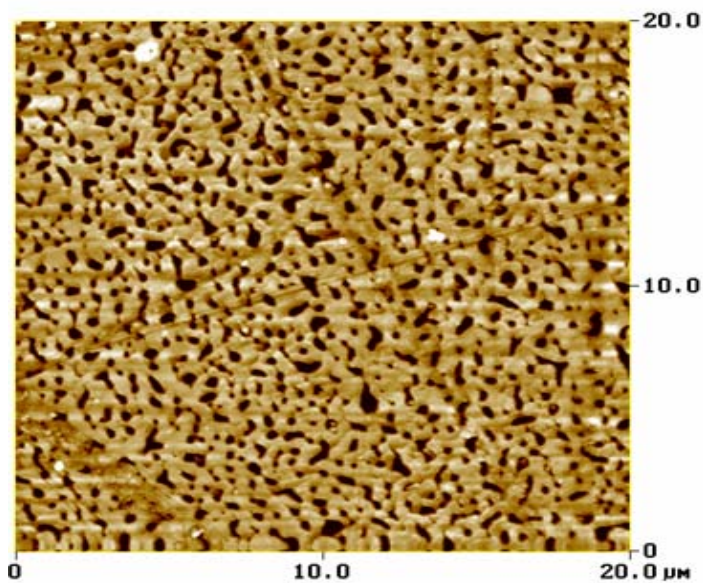
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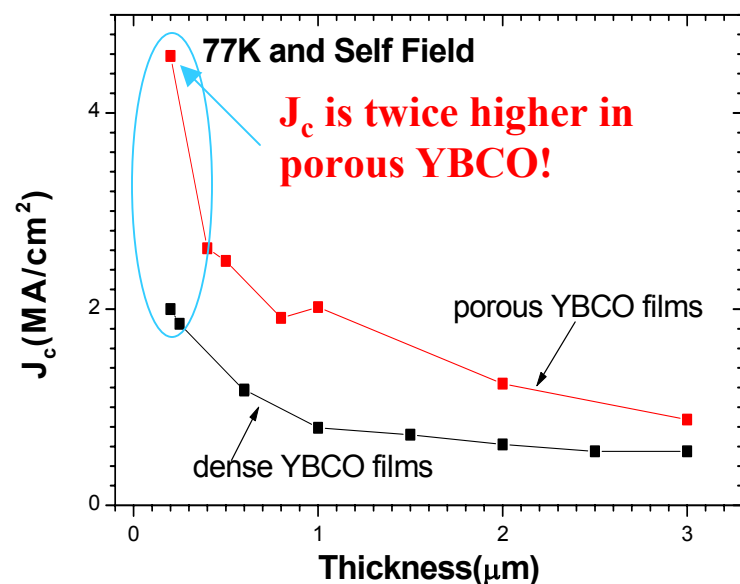
DMR 0206792

- Normally, high T_c superconductor films have a dense structure.
- Highly porous $\text{YBa}_2\text{Cu}_3\text{O}_7$ films obtained by the PI's group using novel processing (substrate miscut and nanoparticle insertion, both for controlling strain at a microscopic scale) can carry significantly higher critical current than their dense-structured counterpart. While the mechanism is still under investigation, the increased surface area in porous HTS films is believed to greatly enhance magnetic vortex pinning, which results in higher J_c .

Porous superconductor films carry significantly higher supercurrents!



AFM image of a porous $\text{YBa}_2\text{Cu}_3\text{O}_7$ thin films on SrTiO_3 substrate.



Superconducting critical current density (J_c) as function of film thickness in porous YBCO films as compared with their dense-structured counterparts

Nano-engineering method for fabrication of porous YBCO films

Superconducting current density (J_c) is one of most important parameters for a superconductor and high J_c s are usually desired for various applications. The best as-grown thin (thickness ~ 0.2 - $0.3\mu\text{m}$) $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO, one of the high temperature superconductors which has received the most extensive study so far) films have J_c s typically in the range of a few MA/cm^2 at 77 K and self field, almost an order of magnitude smaller than the theoretically predicted “depairing J_c ”. It should be pointed out that the fabrication process for YBCO films has been optimized during the past 10-15 years. Improving J_c in YBCO films through regular processing optimization seems unlikely.

A recent study on the thickness dependence of J_c in YBCO films has revealed a puzzling monotonic decrease of J_c with film thickness. J_c in HTS films experiences typically a factor of 3-5 reduction when the film thickness is increased from $0.2\mu\text{m}$ to about $1.0\mu\text{m}$. This feature seems qualitatively “universal” to YBCO films made with various techniques and persists despite the improvement made in achieving uniform physical properties such as T_c and microstructure across the thickness. The question is: what differentiates thick YBCO (or in general, HTS) films from thin ones and hence provides the latter with dramatically higher current density capability?

An obvious difference is in the effect of surfaces, which is much greater in the thin film case. When a current is applied to a superconducting film, Josephson vortices generated have their long side parallel to the surface of the film and pinned by the surface before J_c is reached. Since surface pinning is much stronger than defect pinning, it is plausible to argue that J_c is determined by surface pinning in thin YBCO films. With increasing film thickness, the effect of surface pinning decreases and so does the J_c . To investigate this hypothesis, the PI's group has developed a method to grow porous YBCO films; the idea is to add an enormous amount of surface area in YBCO films so as to (1) further increase J_c in thin films and (2) reduce thickness dependence of J_c .

The method has two important components, substrate miscut and nanoparticle insertion, both for controlling strain at a microscopic scale. On miscut substrates, YBCO films grow at a tilt angle with respect to the normal of the film, and the strain induced generates large size pores only at large film thickness. There is however little control on the pore dimension and density. To overcome this difficulty, Y_2BaCuO_5 (211) nanoparticles were inserted in situ after several monolayer growth of YBCO, which uniforms the strain generated in miscut films and introduced more localized strain from large lattice mismatch between YBCO and 211 ($\sim 7\%$). The 211 nanoparticles were generated in situ in multilayer-type of growth of YBCO and 211 in vacuum based processes such as pulsed laser deposition. When grown alternatively with YBCO, 211 forms nanoparticles of lateral dimension of 20-40 nanometer, instead of a continuous layer because of the large lattice mismatch with YBCO.

This is the first time that a HTS “sponge” was obtained. The J_c achieved in porous YBCO films is significantly higher than the best so far achieved. At $0.2\text{ }\mu\text{m}$ thickness, the porous YBCO film carries twice higher J_c than the best dense-structured film does. This result is by no means optimized but raises a further question on what characteristic length scale governs the J_c flow. It should be realized that the current path is reduced to a much smaller scale on the order of micrometers in the porous films we have obtained. Will J_c continue to increase if the dimension of the current path is further reduced to that comparable to or smaller than the magnetic penetration depth? Can we reach the “depairing” J_c ultimately? Answering such questions will be the focus of our future research.

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Education:

Education has been an important component in this NSF supported project. Three graduate students (Rose Emergo, Xiang Wang and Javier Baca) and one undergraduate (Alan Dibos) have participated in the research. The work has involved collaborations with the US Air Force Research laboratory and the Oak Ridge National laboratory, providing students with special opportunities.

Undergraduate Research



Undergraduate Alan Dibos and Jason Brookman were working on scanning electron microscope (LEO1550) to characterize HTS films made using a new nano-processing method.